Naturvetenskapliga
fakulteten

Assessing important technical risks from use of a floating wind turbine unit equipped with pumps for oxygenation of the deepwater

Technical report no.5

Holger Eriksson &
Thomas Kullander

C99
Rapport
Gothenburg 2013

Department of Earth Sciences
University of Gothenburg

GÖTEBORGS UNIVERSITET

UNIVERSITY OF GOTHENBURG
Department of Earth Sciences
Geovetarcentrum/Earth Science Centre

Assessing important technical risks from use of a floating wind turbine unit equipped with pumps for oxygenation of the deepwater

Technical report no.5

Holger Eriksson &
Thomas Kullander

ISSN 1400-383X

C99
Rapport
Gothenburg 2013

Mailing address
Geovetarcentrum
S 405 30 Göteborg

Address
Geovetarcentrum
Guldhedsgatan 5A

Telephone
031-786 19 56

Telefax
031-786 19 86

Geovetarcentrum
Göteborg University
S-405 30 Göteborg
SWEDEN

Abstract

This report serves to assess and report the significant technical risks associated with the design, construction, installation, operation, maintenance and decommissioning of a floating Demonstrator wind turbine and pumping unit located in the Bornholm Basin of the Baltic proper. The assessment is based on the proven design and mitigated risks of the Hywind I which has shown to be safe, reliable, durable, robust, clean and cost-efficient.

The report is applicable for the proposed locations presented in Technical Report no. 2 (Ödalen and Stigebrandt, 2013) of the BOX-WIN series of reports, where water depth is approximately 100 meters and seabed soil is pre-dominantly clay and sand.

Risks are identified, analysed and evaluated qualitatively according to the method of Preliminary Hazard Analysis (PHA) and are rated by the product of the probability of the event and the consequence of its occurrence.

The risks evaluated in this report are directly related to the location of the Demonstrator in the Bornholm Basin and introduction of pumping device to the proven Hywind I design, for example that the dynamic cable is ripped off or compressed to knuckle, that the Demonstrator is removed off location due to excessive horizontal ice loads at a severe ice drift condition, that the Demonstrator turns upside down as the intact stability is reduced due to icing of the wind tower and rotor blades, and that the replacement of pumps is difficult, delayed or impossible to undertake due to the underwater installation and movements of the Demonstrator.

The risk assessment of the proposed conceptual design of the Demonstrator has not revealed adverse technical risks beyond those already resolved by the offshore, maritime and wind power industry.

Complementary risk reducing actions shall be taken and additional risk assessments shall be performed in the Basic Design phase, like the FMEA, HAZID and HAZOP analyses.

Sammanfattning

Denna rapport syftar till att behandla de väsentliga tekniska riskerna för konstruktion, byggnation, transport, installation, drift, underhåll och borttagande av en Demonstrator – en flytande vindkraftsdriven pumpanläggning placerad i Bornholmsbassängen i egentliga Östersjön. Riskbedömningen bygger på den beprövade och riskaverta konstruktionen av det flytande vindkraftverket Hywind I vilken har visat sig vara säker, pålitlig, robust och kostnadseffektiv, samt ha liten inverkan på havsbotten.

Den tilltänkta lokaliseringen framgår av Technical Report no. 2 (Ödalen and Stigebrandt, 2013) som ingår i BOX-WIN serien av tekniska rapporter, och avser ett vattendjup av ungefär 100 m och en havsbotten bestående av lera och sand.

Riskerna har identifierats, analyserats och bedömts kvalitativt enligt metoden for preliminär riskhantering (PHA) och vardera försetts med ett risktal motsvarande produkten av sannolikheten för att risken inträffar och konsekvensen av vad som då sker.

De risker som har bedömts i denna rapport är direkt hänförda till placeringen av Demonstratoranläggningen i Bornholmsbassängen och införandet av en pumpanordning till den beprövade konstruktionen av Hywind I, t.ex. att kraftkabeln dras av eller knäcks i infästningen till Demonstratorn, att Demonstratorn flyttas ur förankrat läge av trycket från isvallar, att Demonstartorn förlorar stabiliteten och tippar på grund av nedisning av vindkrafttornet och rotorbladen, eller att byte av felande pumpar blir besvärligt, försenat eller till och med omöjligt på grund av placeringen under vatten och Demonstartorns rörelser.

Riskbedömningen i den föreliggande genomförbarhetsstudien visar att det inte finns några allvarliga tekniska risker hos den föreslagna Demonstratoranläggningen. Tänkbara risker har redan lösts, helt eller delvis, inom offshore-, sjöfarts- och/eller vindkraftsindustrin, så inga synnerliga restrisker som innebär allvarliga hinder mot genomförandet kvarstår.

Vid framtagandet av grundkonstruktionen skall flera riskanalyser göras, bl.a. FMEA; HAZID och HAZOP i syfte att minimera restriskerna.

Table of Contents

List of tables

Preface

In 2008, Formas and Naturvårdsverket (Swedish EPA) announced available funding for research on the possibility to use deepwater oxidation as a mean to combat eutrophication in the Baltic Sea. Two projects, BOX, “Baltic deepwater OXygenation” and PROPPEN were funded at the end of December 2008. These projects have shown that phosphorus leakage from anoxic bottoms in small coastal basins may be stopped by oxygenation. BOX has shown that this also is true for the Baltic proper. The BOX-WIN project “winddriven oxygenation by pumping and generation of electrical power” builds on BOX.

Results from the BOX-WIN project will be presented in a series of reports from the Department of Earth Sciences at University of Gothenburg. A wide range of subjects are covered by BOX-WIN. Technological, environmental, economical and legal facts and circumstances must be considered to develop and locate a full-scale Demonstrator composed of a self-supporting, floating wind turbine unit with a generator producing electric power for deepwater oxygenation by pumping and for delivery to the grid. The Demonstrator will be developed for the Bornholm Basin, which at times has anoxic water in its deepest parts. The Demonstrator developed by BOX-WIN will hopefully be built to conduct tests in the Bornholm Basin. This would be an important step towards installation of a regional system of full-scale floating wind turbine units with pumps in the Bornholm Basin. An updated list of BOX-WIN reports is included at the end of the report.

The present report “BOX-WIN Technical report no. 5 – Assessing important technical risks from use of a floating wind turbine unit equipped with pumps for oxygenation of the deepwater” is written by Holger Eriksson and Thomas Kullander. The work is funded by the Swedish Agency for Marine and Water Management.

Gothenburg 12 March 2013

Anders Stigebrandt

1. Introduction

This report serves the purpose to assess and report the significant technical risks associated with the design, construction, installation, operation, maintenance and decommissioning of a floating Demonstrator wind turbine and pumping unit located in the Bornholm Basin of the Baltic proper. Risks associated with environmental impact, legal impediments, political decisiveness, social acceptability and economical pay-off will be evaluated in a later stage of the project.

This feasibility study of a Demonstrator is based on the proven design of the Floating Wind Turbine Unit (FWTU) named Hywind, which has been moored in the Norwegian Sea west of Bergen, Norway at 500 meters of water depth and operated continuously since 2009. The Hywind FWTU is referred to as Hywind I herein. Its design has been modified to accommodate a water pumping device for deepwater ventilation on an assigned location in the Bornholm Basin of the Baltic proper. The report is thus applicable for the proposed locations presented in Technical Report no. 2 (Ödalen and Stigebrandt, 2013)[1] of the BOX-WIN series of reports, where water depth is approximately 100 meters and seabed soil is pre-dominantly clay and sand.

The task objective of this feasibility study is to assign important technical functions of the Demonstrator concept to the lowest residual risk, i.e. on Green Level. It is to be noted that this target is not necessarily coherent to other potentially attractive or even mandatory goals, e.g. to obtain the lowest cost or gain the maximum performance.

The risk strategy is distinctively avert and relies almost exclusively on known technology from proven design of floaters used in the maritime and offshore industry. However, where a design has not been proved in floaters, it should preferably have been used in fixed offshore platforms; and in case the design has not been introduced offshore or to marine vessels at all, the comparative application onshore is advised but then to a higher risk. Unknown or new technology has been avoided on the whole.

Risks have been assessed based on the international standard ISO 31000[2] and identified, analysed and evaluated qualitatively according to the method of Preliminary Hazard Analysis (PHA).

2. Data

Design data and conceptual design drawings form the basis for the risk assessment. Some design data are published in Technical Report no. 4 of the BOX-WIN series of reports.[3] The conceptual design drawings and other design data will be published in the upcoming report "Plan and Cost Estimate for a Demonstrator", which will also be a Technical Report in the BOX-WIN series.[4] This report will also include investigations of patent and immaterial rights and a preliminary cost estimate for the construction of the Demonstrator.

3. Preliminary Hazard Analysis

The Preliminary Hazard Analysis (PHA) is based on the risk evaluation matrix in Table 1.

The risk rating is equal to the probability of the event times the consequence of its occurrence, i.e. its impact. For example, according to the table an event which is not very probable to occur (e.g. probability rating is 2) but whose consequences fit the description of a severe event (e.g. impact rating is 4), will have a risk rating of 8 (i.e. qualify for the yellow level).

Thus, all undesirable events receive a risk rating from 1 to 25, where

1 - 4	Green Level, need no further attention
5 - 12	Yellow Level, risk reducing action is to be evaluated
13 - 25	Red Level, risk reducing action is required

The PHA is a systematic assessment of the initial risks followed by the residual risks. By first calculating the rate of initial risks, which result in a number from 1 to 25 as described above, any further action to reduce the risk is stipulated by the level colour. For example, a Red Level risk corresponds to a risk rate number from 13 to 25 and must be accompanied by the assessment of any possible residual risk in order to make this risk acceptable, i.e. degraded to the Yellow or Green Level.

For the purpose of this Conceptual Design, risks are assessed without tasks assigned to them.

Table 1. Risk Evaluation Matrix.

Consequence (Impact)					**Probability**				
Severity	Personnel (P)	Environment (E)	Assets (A)	Reputation (R)	1 Improbable	2 Not very probable	3 Probable	4 Frequent	5 Very frequent
1 Slight	Slight health effect or injury. (First aid)	Insignificant pollution.	Slight damage. Cost up to: 5×10^3 SEK	Slight impact. No public concern.	🟩 **1**	🟩 **2**	🟩 **3**	🟩 **4**	🟨 **5**
2 Moderate	Minor health effect or injury. (Lost Time Injury 1 day or less)	Minor pollution. Restoration time up to 1 month.	Minor damage. Cost up to 50×10^3 SEK	Limited impact. Some public concern.	🟩 **2**	🟩 **4**	🟨 **6**	🟨 **8**	🟨 **10**
3 Major	Major health effect or injury. (Affect work performance in the longer run)	Moderate pollution. Restoration time 1 month to 1 year.	Local damage. Cost up to 500×10^3 SEK.	Considerable impact Regional public concern.	🟩 **3**	🟨 **6**	🟨 **9**	🟨 **12**	🟥 **15**
4 Severe	Permanent and Total Disability or 1 fatality	Large pollution. Restoration time 1 to 10 years.	Major damage. Cost up to 5 MSEK.	National impact. National public concern.	🟩 **4**	🟨 **8**	🟨 **12**	🟥 **16**	🟥 **20**
5 Extensive	Multiple fatalities	Very large pollution. Restoration time over 10 years.	Extensive damage. Cost over 5 MSEK.	International impact and negative exposure. International public concern.	🟨 **5**	🟨 **10**	🟥 **15**	🟥 **20**	🟥 **25**

4. Technical Risks

The technical risks involved in the design, construction, installation, operation, maintenance and decommissioning of a Demonstrator have been assessed. It corresponds to the asset (A) risk of the risk matrix as illustrated by Table 1. Additional risk categories have not been assessed, such as safety risks for the personnel (P) involved with the production, installation or operations offshore; impact risks on the environment (E) surrounding the production facility and the location on site, and risks of negative publicity (R).

4.1 Hywind Risks

The risks associated with Hywind I have already been assessed by Statoil A/S, the owner of Hywind I and II, and assigned with a qualified or quantified residual risk. Consequently these risks are indifferent to the Demonstrator and need not be re-assessed until the Basic Design phase. For this reason, only risks which are directly attributable to the particular “new” design features of the Demonstrator have been assessed; these risks are therefore new or different and their mitigation supplementary to that of Hywind I. It is understood that this feasibility study is not authorized to check or review the risks ratings of Hywind I, which are the intellectual property of Statoil A/S.

During the development of the Demonstrator, Statoil A/S has not indicated any doubt or presented any non-manageable residual risks that would potentially jeopardize the Demonstrator concept as based on Hywind I. Neither has such objections materialized in any other context. On the contrary and prior to the BOX-WIN project, Statoil A/S has started the development of the Hywind II concept to meet global market requirements for increased effect and reduced draught, all in line with the prevailing design assumptions of the Demonstrator. So, this risk assessment is focused on the novelty of the Demonstrator and indifferent risks hereto being disregarded as insignificant at this early stage of design. For example, risks associated with the location of the Demonstrator, such as the draught margin and ice formation, or with malfunction of the pumping units are assessed in this report, whereas risks attributable to fire, collision, boarding, etc. are left out as they are applicable to all potential FWTU’s and not uniquely to the Demonstrator, nor critical to the task objective. The significance of these risks will anyway be assessed at the HAZID and HAZOP analyses in the Basic Design phase.

4.2 Demonstrator Risks

The location and malfunction risks are unique for the Demonstrator as compared to Hywind I.

The Demonstrator is located in the Bornholm basin which primarily brings on risks induced by the environment. During hard winters, the sea water and air temperature is often lower than that of the Norwegian Sea due to a pre-dominant inland climate. By gale wind from east, ideal conditions appear for ice drift upwind from the open Baltic proper and icing of the Demonstrator. In addition, due to a lower water depth as compared to Hywind I, less free water is available below the keel; e.g. a smaller margin to the seafloor, which increases the risk for grounding or disturbance to the seabed soil due to wrongly directed water jet trajectories from the outlets. Another distinction from the Hywind I location is the length of dynamic cable catenary, which is much shorter due to a smaller water depth.

New functions of the Demonstrator are primarily related to the pumping facility, with water inlet at mid-depth and outlet near the bottom, and its effect on the oscillation frequency of the unit. Although pumps are designed for small lifting height (about 1 m) and large mass flow, both of which are known and proven technologies onshore, the submerged version of these are not known to be installed offshore. Design, access and replacement of the pump body as well as normal operation and planned maintenance of the same are known technology but yet to be applied offshore. Water intake and separation roof are basically novel designs offshore but are not considered to impact the feasibility of the Demonstrator, nor do the design of outlet nozzles. The shape of the substructure is novel and will interact with the mooring system and impact the motions, stability and oscillation frequencies of the Demonstrator.

For evaluation of the risk rates, the design life of the Demonstrator is set to be 20 years.

5. Risk Assessment Results

In each of the following subsections, the undesired event related to the section topic will be evaluated.

5.1 Risk of Location

5.1.1 Draught Margin

The undesired event assessed in this section is the disturbance of the seabed soil due to grounding of the Demonstrator or wrongly directed water jet trajectories.

The draught is about 85 m when water depth on location is 95 m, i.e. the nominal sea floor margin is 10 m. This distance is large enough to accommodate the motions of the Demonstrator, cope with extreme water tables (HHW +1,67 m and LLW -1,44 m, see Bergdahl (2002)[5]), and allow for the necessary sea floor margins and possibility for wrongly directed water jet trajectories of the Demonstrator when being moored at a maximum angle of inclination. The motions are directed both vertically (heave) and horizontally (sway and surge) as these are excited by the environmental loads, particularly from wind and sea waves, and regulated by the stiffness of the mooring system.

At large horizontal loads, derived from parallel wind and waves, or wind and ice drift, the Demonstrator may set off approximately maximum 10 m and incline up to 7 degrees in undamaged condition. These values depend on the mooring system design and exact figures will be calculated in the Basic Design phase. In this harsh condition, should a compartment of the Demonstrator be flooded due to collision impact from a supply vessel or ice, and in addition one pump will fail; this would increase the draught due to loss of displacement of the damaged compartment, and potentially further increase the angle of inclination depending on the location of damage and failed pump. The probability of these simultaneous undesired events, and the impact thereof, will be assessed quantitatively in the Basic Design phase.

The risk rate is assessed to:

- probability = 2, impact = 4, risk rate = 8 (yellow)

The draught margin will be verified by displacements and loads obtained from the mooring analysis, motions from the hydrodynamic analysis, angles of inclination from the damage stability calculation and ice loads from the ice drift calculation; all performed in the Basic Design phase.

Several risk reducing actions are possible, e.g. to direct the outlet nozzles somewhat upwards from the nominal horizontal trajectories of the water jets, to reduce the water outlet velocity by increasing the total cross-sectional area and radial distance to the Demonstrator centreline of the outlet nozzles, to reduce the size of a potentially damaged compartment, to adjust the vertical position of the mooring suspension points and to avoid mooring the Demonstrator in a deep water hollow of radius less than approximately 200 m. A computational fluid dynamic (CFD) analysis will optionally be performed in the Basic Design phase to verify the in situ sea floor geometrics of the location.

The residual risk is assessed to:

- probability = 2, impact =3, risk rate = 6 (yellow)

5.1.2 Ice Drift

The undesired event related to ice drift is that the Demonstrator is removed off location by too large horizontal ice loads at a severe ice drift condition, which the mooring system cannot withstand.

Ice ridges are reported from the waters around the location. These are mainly the result of a severely cold winter and strong winds from large ice-covered areas upwind (particularly to the east). The report by Bergdahl (2002)[5] describes a maximum 25 % of probability for 30 cm of ice in the waters around the location and a maximum 10% of probability for a severely cold winter with ice-covered waters in the South Baltic Sea, which is east of the location of the

Demonstrator in the Bornholm Basin. A similar assessment is made by Ödalen and Stigebrandt (2013) in BOX-WIN Technical Report no. 2.[1] The probability of ice ridges at the location has been conservatively assessed to once every 10 years.

The risk related to ice loads is assessed to:

- probability = 2, impact = 5, risk rate = 10 (yellow)

The holding capacity of the mooring system and ice loads will be calculated in the Basic Design phase.

Several risk reducing actions are possible, e.g. to relocate, increase and extend the conicity of the outer hull in the splash zone and to structurally reinforce the splash zone to meet the rules and regulations for ice classed vessels, which allows the Demonstrator to break ice also at some angle of inclination in direction of the ice press; to provide the Demonstrator with a winter draught mark, which may increase the draught but ultimately shut down the FWTU at too a high ice press; to request assistance from an icebreaking supply vessel or the like to break the ice to windward or push the Demonstrator on the leeward side against the ice during periods of potential high ice press from ice ridges. Model tests or computer simulations may be required in the Basic Design phase to verify the icebreaking capacity of the Demonstrator, also at considerable angles of inclinations. From these results, the required bollard pull of the icebreaking vessel can be estimated. The cost of periodic icebreaking vessel assistance is presumably high.

The residual risk is assessed to:

- probability = 2, impact =3, risk rate = 6 (yellow)

5.1.3 Icing

The undesired event related to icing is loss of intact stability, which may ultimately tip the Demonstrator upside down, due to increased weight from built up of ice on the outer shell of the wind tower and on parts the turbine blades. Build-up of ice may result from a combination of winter storm, ice-free waters and supercooled rain or very cold weather.

This winter condition adds weight to the upper hull compared to the summer condition, which requires an increased metacentric height of the Demonstrator during winter time. It is known that accelerations increase with a shorter roll and/or pitch period which are the effect of an increased metacentric height. Should the summer and winter draught assumingly be the same, increased horizontal accelerations would imply unnecessary loads on the wind power turbine and turbine blades atop in the summer. This would require reinforced equipment and structural support, which put additional weight to the nacelle and again add loss of stability, and so on. Icing of the turbine blades would imbalance the rotor, which may ultimately shut down the FTWU. Also, cost would add to the equipment of the FTWU. Guidelines for calculation of the added weight due to icing are included in Bergdahl (2002)[5].

The risk is assessed to:

- probability = 2, impact = 5, risk rate = 10 (yellow)

Some risk reducing actions are possible, e.g. to include heating cables in the blades or operate on a winter draught different from that of the summer, or to compensate for the added weight of ice by reducing the corresponding mass of potential water ballast above the water line by means of an automatic ballast control system. To permanently operate a too stiff FWTU should be checked in the Basic Design phase, but that is generally not a first option as described above.

The residual risk is assessed to:

- probability = 2, impact = 2, risk rate = 4 (green)

It is to be noted that different draught marks mean different tension in the mooring system which is suspended by means of fixed pad eyes, as per BOX-WIN conceptual design[3,4]; or alternatively, unchanged tension in the mooring system which would, as per offshore standards, require a vertically adjustable mooring system suspended by means of fairleads and anchor winches. The latter is considerably more costly to procure and would require some sort of automatic mooring tension system to avoid manual operation, all of which are not recommended by BOX-WIN[3]. Different draught marks will also mean different draught margins, thus optimum water mixing will not be obtainable all year around. Also for this reason, a constant draught is recommended for the Demonstrator.

5.1.4 Dynamic Cable Length

The undesired event assessed in this section is that the dynamic cable is ripped off or compressed to knuckle.

Hywind I is moored at about 500 m of water depth, with the dynamic cable hung off in dry position, well above the water line. That gives a dynamic cable length of approximately 600 m which is enough to accommodate the vertical heave and horizontal sway motions of the Hywind I. The dynamic cable of the Demonstrator is hung off onto the outer shell just below the water inlet, i.e. at about half the draught or 50 m above the seafloor. Assuming the dynamic cable is connected to the static cable on the seafloor at about 50 m off the Demonstrator, this is too short a distance to accommodate the predicted maximum set off of the Demonstrator.

The risk of damage to the dynamic cable is assessed to:

- probability = 4, impact = 4, risk rate = 16 (red)

The risk reducing action in this case is known to the offshore industry and is achieved by the dynamic power cable being arranged in a lazy S, i.e. supported by a separate submerged buoy floating at about 50 m of water depth between the Demonstrator and the static power cable connection located on the seafloor at about 200 m off the Demonstrator. The dynamic cable will thus hang freely in one loop between the Demonstrator and the buoy, and in a catenary curve from the buoy to the seafloor connection to the static cable. This arrangement allows the dynamic cable to adjust to the different set off positions of the Demonstrator.

The residual risk is assessed to:

- probability = 4, impact = 1, risk rate = 4 (green)

5.2 Risk of Malfunction

5.2.1 Pump Failure

The undesired event related to pumping is malfunction of any of the submerged pumping units.

The Demonstrator comprises a water pumping facility by basically adding three vertical cylinders to the vertical steel cylinder of Hywind I[4]. These three cylinders are positioned in rotational symmetry around the centreline of the central vertical steel cylinder and constitute three separate water channels. Each of these houses a separate pumping device which allows the Demonstrator to pump oxygen saturated water from above the oxycline to the sea bottom. The pumping device comprises a pump which is powered by a motor enclosed by a watertight pumping body located above the inlet to the water channel. This channel is curvilinear to the horizon and screened off from waters atop the oxycline by a structural separation roof, but also curvilinear to the horizon above the sea bottom and has its lower end equipped with nozzles for directing the outlet water jets optionally slightly upwards.

There are several potential sources of pump failure, e.g. pump blade failure if blades are caught by drifting stocks or fishing nets, leaking lubrication, a non-watertight pumping body, etc.

The risk of pump failure is assessed to:

- probability = 3, impact = 3, risk rate = 9 (yellow)

Some risk reducing actions are possible in the Basic Design phase, like the insertion of an inlet lattice and introduction of a pump control system, and conducting quantitative (FMEA) and qualitative (HAZID) risk analyses.

The residual risk is assessed to:

- probability = 2, impact = 2, risk rate = 4 (green)

5.2.2 Pump Replacement

The undesired event is an unplanned replacement of a pumping body that is difficult, delayed or impossible to undertake.

It is assumed that the HAZOP risk assessment meeting held in the Basic Design phase will show that all tree pumping devices need to be operational at the same time in order to avoid unacceptable inclination or gyration of the Demonstrator, which would potentially be the effect if one pump is malfunctioning. The failing pump then needs to be replaced with short notice.

The risk for pump replacement under non-optimal conditions is assessed to:

- probability = 3, impact = 3, risk rate = 9 (yellow)

Some risk reducing actions are possible in the Basic Design phase, e.g. by assistance of a device for lifting the submerged watertight pumping body to the surface on-board a supply vessel for replacement. The device may be attached to the Demonstrator or to the supply vessel.

The residual risk is assessed to:

- probability = 3, impact = 2, risk rate = 6 (yellow)

5.2.3 Oscillation

The undesired event related to oscillation is shut-down of the FWTU due to potentially exaggerated oscillations of the submerged body, including mooring system and dynamic power cable, coincident with the rotor or wind tower frequency in operation.

The shape of the substructure gives rise to a different distribution of displacement compared to Hywind I and the corresponding hydrodynamic motions and loads.

The risk of problems caused by such oscillations is assessed to:

- probability = 2, impact = 5, risk rate = 10 (yellow)

It is known technology to couple several free-floating submerged bodies in a wave and wind spectrum and derive the loads and motions, and also to calculate the oscillations of a FWTU, based on these environmental impacts. Such risk reducing iterative computations will be performed in the Basic Design phase to verify the eigenfrequences to avoid for the Demonstrator.

The residual risk is thus assessed to:

- probability = 2, impact = 2, risk rate = 4 (green)

6. Conclusion

The proposed conceptual design of the Demonstrator possesses no adverse technical risks beyond those already resolved by the offshore, maritime and wind power industry.

The initial technical risks assessed are rated on the Red and Yellow Level (see Table 2), which means that these shall or should be evaluated for reduction. The residual risks are all down-rated and four of them are on the Green Level while the rest are still on the Yellow Level. For these, additional risk reducing actions than those described in this report are yet to be evaluated in the Basic Design phase of the Demonstrator.

Table 2. Rates of Risk.

Risk Item	**Initial Risk**	**Residual risk**
Draught Margin	8	6
Ice Drift	10	6
Icing	10	4
Dynamic Cable Length	16	4
Pump Failure	9	4
Pump Exchange	9	6
Oscillation	10	4

7. Acknowledgements

This work was funded by the Swedish Agency for Marine and Water Management.

8. References

1. Ödalen, M. & Stigebrandt, A., 2013. Factors of potential importance for the location of wind-driven water pumps in the Bornholm Basin, BOX-WIN Technical Report no. 2, Report C97, ISSN 1400-383X, Dept. of Earth Sciences, University of Gothenburg.
2. ISO 31000:2009 ”Risk Management – Principles and Guidelines”
3. Eriksson, H., Kullander, T., 2013. Assessing feasible mooring technologies for a Demonstrator in the Bornholm Basin as restricted to the modes of operation and limitations for the Demonstrator, BOX-WIN Technical Report no. 4, Report C98, ISSN 1400-383X, Dept. of Earth Sciences, University of Gothenburg.
4. Eriksson, H., Kullander, T., 2013. Plan and Cost Estimate for a Demonstrator, BOX-WIN Technical Report series. (in prep.)
5. Bergdahl L., 2002. Islaster på vindkraftverk till havs, Beskrivning av mekanismer och rekommendationer för dimensionering, Rapport nr 2002:1, Chalmers Tekniska Högskola, Vatten Miljö Transport, Göteborg, 39 pp. (in Swedish)

BOX-WIN Technical Reports Series

1. Ödalen, M. & Stigebrandt, A., 2013. Hydrographical conditions in the Bornholm Basin of importance for oxygenation of the deepwater by pumping down oxygen saturated water from above the halocline, BOX-WIN Technical Report no. 1, Report C96, ISSN 1400-383X, Dept. of Earth Sciences, University of Gothenburg.

2. Ödalen, M. & Stigebrandt, A., 2013. Factors of potential importance for the location of wind-driven water pumps in the Bornholm Basin, BOX-WIN Technical Report no. 2, Report C97, ISSN 1400-383X, Dept. of Earth Sciences, University of Gothenburg.

3. Stigebrandt, A., Kalén, O., 2012. Improving oxygen conditions in the deeper parts of Bornholm Sea by pumped injection of winter water, *Ambio,* 41, no. 8, Dec 2012, doi: 10.1007/s13280-012-0356-4 (BOX-WIN Technical Report no. 3)

4. Eriksson, H., Kullander, T., 2013. Assessing feasible mooring technologies for a Demonstrator in the Bornholm Basin as restricted to the modes of operation and limitations for the Demonstrator, BOX-WIN Technical Report no. 4, Report C98, ISSN 1400-383X, Dept. of Earth Sciences, University of Gothenburg.

5. Eriksson, H., Kullander, T., 2013. Assessing important technical risks from use of a floating wind turbine unit equipped with pumps for oxygenation of the deepwater, BOX-WIN Technical Report no. 5, Report C99, ISSN 1400-383X, Dept. of Earth Sciences, University of Gothenburg.